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Microturbine Generators for FC/MTG Hybrid Power Systems

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Rapid Birth and Evolution of Distributed Generation Strategy

Base Program launched with DTE Energy Technology March 2000

- Driving DTE Energy Technology's ENT400 package
- DTE Energy: controls, power switching & package
- Turbo Genset Company: generator & inverter
- PWC: ST5 natural gas fuel turbine

Growth path established:

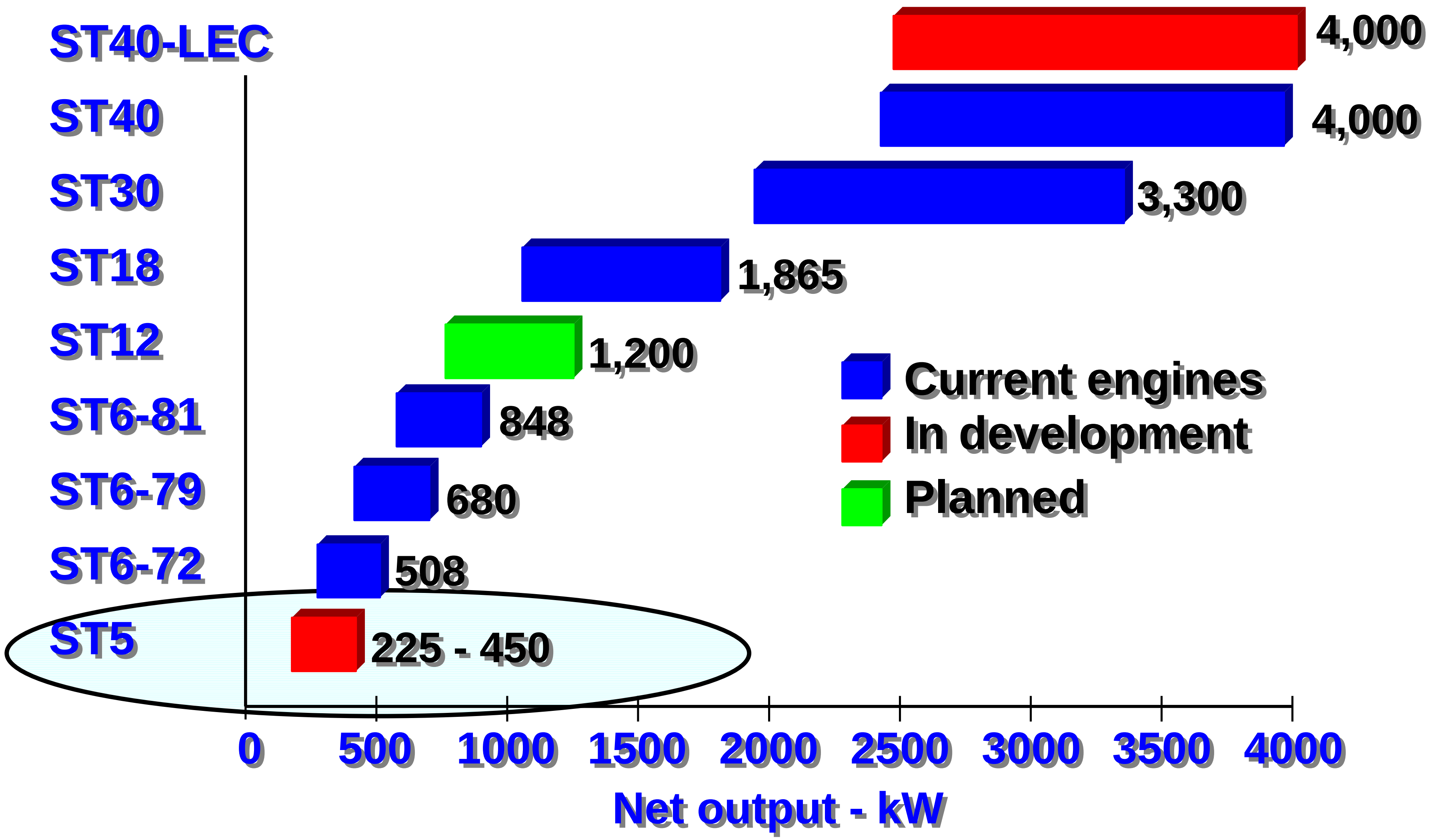
- ✓ Prove out base machine
- Adapt base machine through component improvement
- Couple with bottoming cycle to achieve DOE goal of 40% efficiency

2002 Milestones leading to 40% Electrical Efficiency Demonstration in 2004

- ✓ **Feb 2002: Demonstrate 80 kW from ORC**
- **Aug 2002: Demonstrate 5-point increase in system electrical efficiency with ORC**
- **Sep 2002: Perform integrated microturbine/ORC test (September 02)**
- **Nov 2002: Demonstrate combustor emissions technology for NOx<7 ppm and CO<10 ppm**

P&W INDUSTRIAL PRODUCTS – Base Machine Selection

ISO-BASELOAD POWER

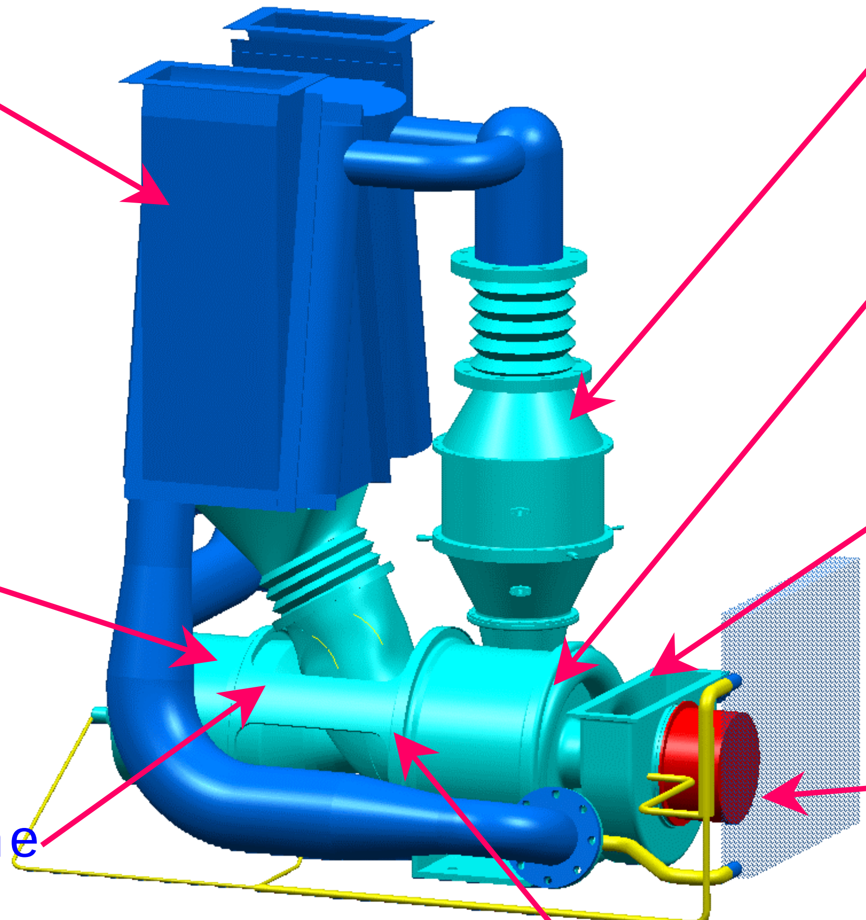


ST5 Engine Package

Recuperator
- Removable for integration with CHP and FC systems

Generator
- gearless high speed generator by TGC

Free Power Turbine
- Improves turn down performance



LEC Combustor

Single stage compressor

Ported Inlet

Starter

Oil-free air bearing system

Base Engine is a High Efficiency MTG

8:1 Pressure ratio - aero based on PW207 but no common P/N

- **Redesigned for low cost production and operation**

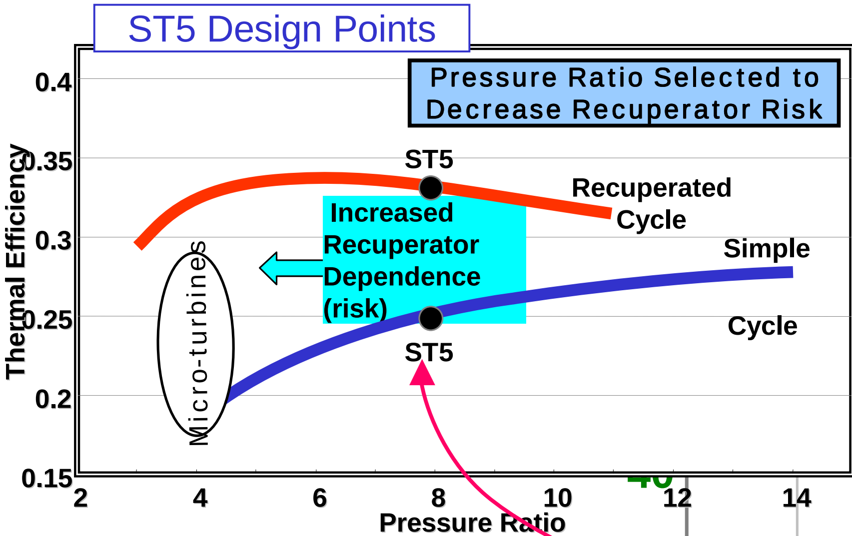
Convertible from recuperated (prime) to simple-cycle

	@ shaft	@ terminals
Rated Power:		
- ISO day, (59ºF) :	467kW	400kW
- Hot day, (95ºF) :	390kW	333kW
Thermal efficiency		
- η recuperated :	34%	30%
- η simple cycle:	24%	22%

Low emissions (base load natural gas fuel)

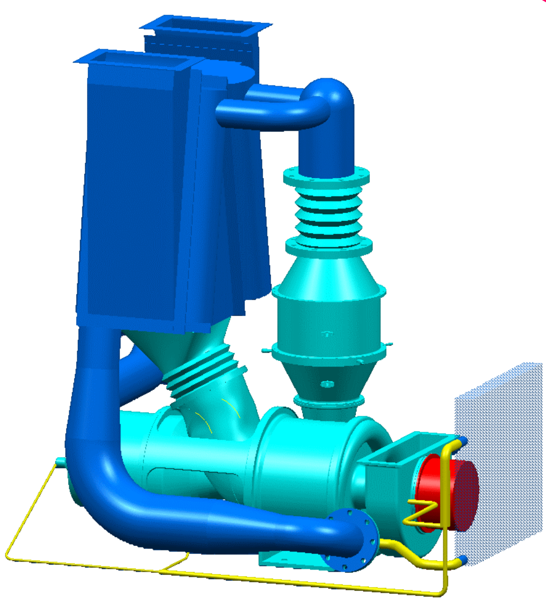
- NOx < 10 ppm CO < 20 ppm UTC Distributed Generation Growth Path Aligned with DOE Goals

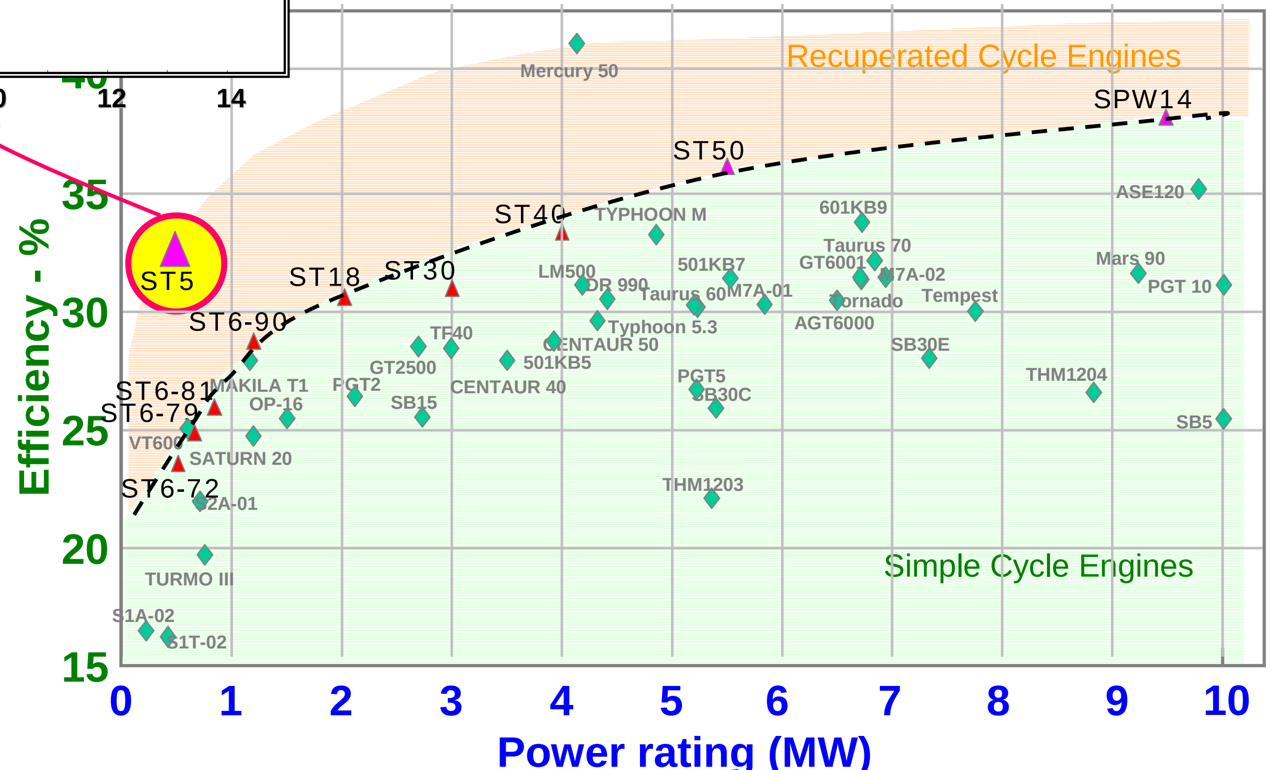
P&WC ENGINES – Proven Performance



ST5 Recuperated Cycle parameters obtain:

- best performance
  - optimal choice of OPR + T4, *with*
- balanced risk
  - recuperator performance vs. specific power, *and*
- achievable component life
  - recuperator materials limits

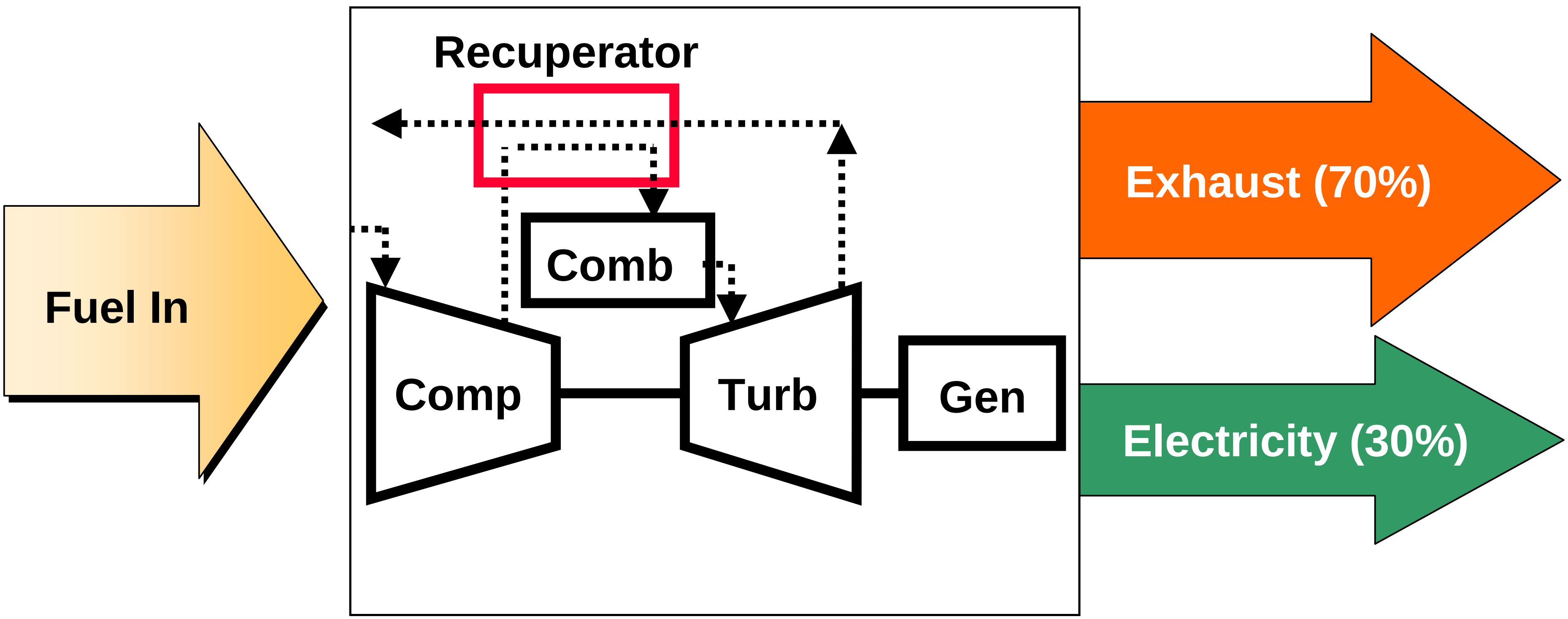




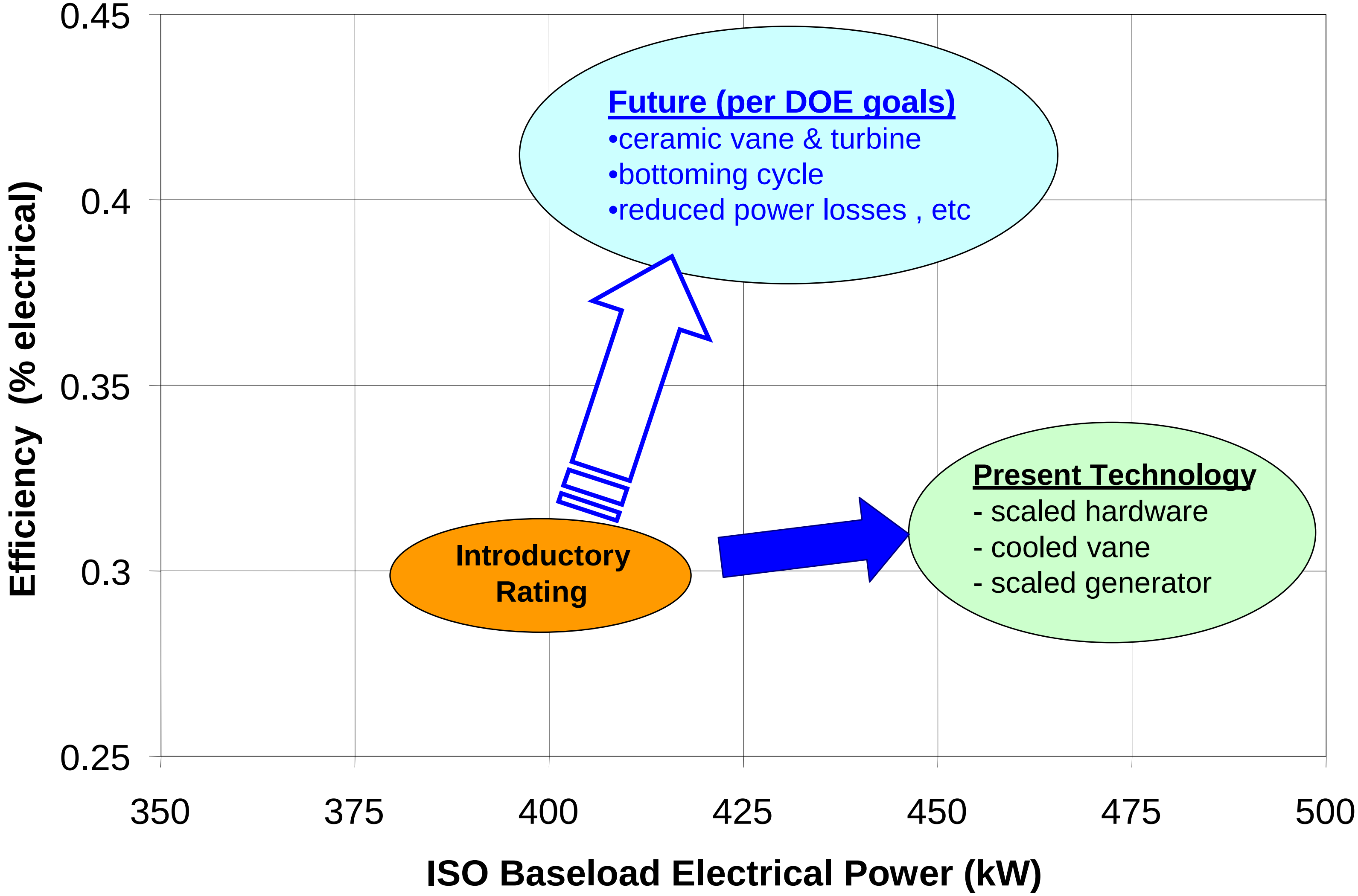
Right System Delivers Affordable Performance

System combines performance and economics

- PWC ST5 drives a 30% electrical efficiency microturbine system
  - Recuperated gas turbine engine @ PR = 8
  - Exhaust flow @ 5 lb/s, ~700F



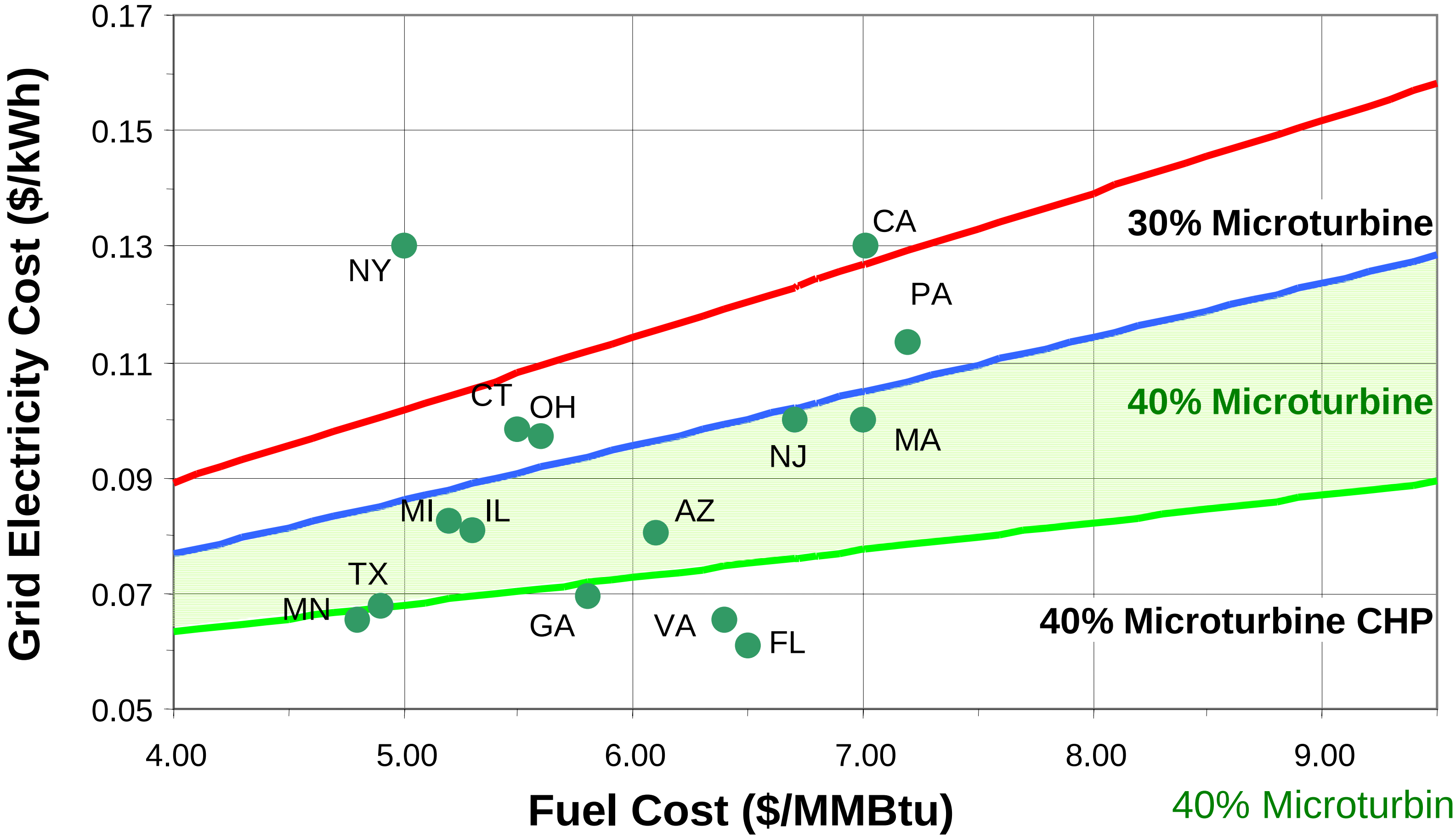
Growth Strategy - Targets High System Efficiency



Target 40% Microturbine Competitive in Many States

Attractive economics for > 30% of US population

- 4-year customer payback of installed equipment @ $700/kW
- No credit taken for reliability, low emissions, or avoided transmission upgrade



40% Microturbine

UTC Distributed Generation Growth Aligned with DOE Goals

DOE Advanced Microturbine System Goals

- Electrical efficiency = 40%
- NOx = 7 PPM on natural gas fuel
- Multi-fuel capability
- 11,000 hour between major overhaul
- System cost = $500US/kW

UTC Approach

- Affordably increase P&W ST5-powered ENT400 microturbine from 30% to 40% electrical efficiency with NOx < 7 ppm
  - Demonstrate practical recuperated cycle
  - Improve selected component efficiency
  - Demonstrate bottoming cycle system efficiency

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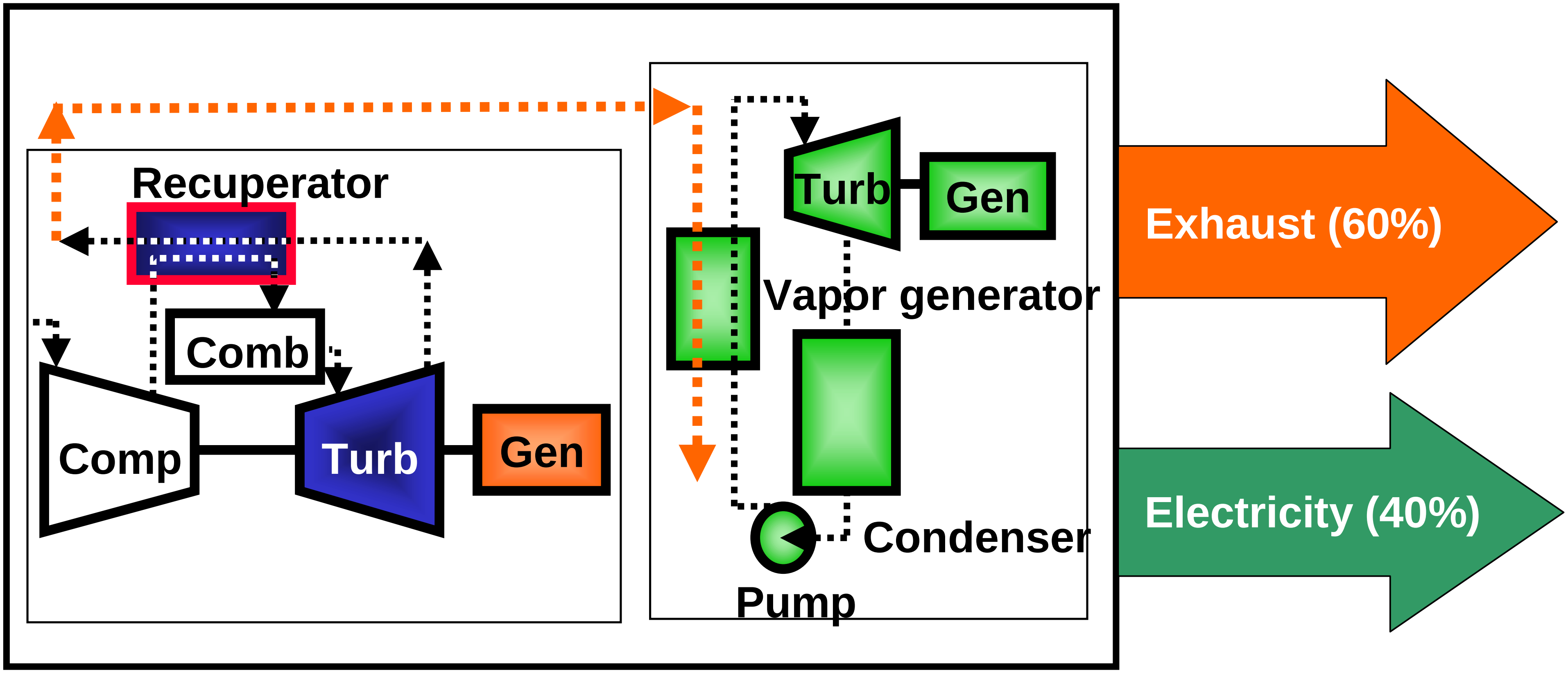
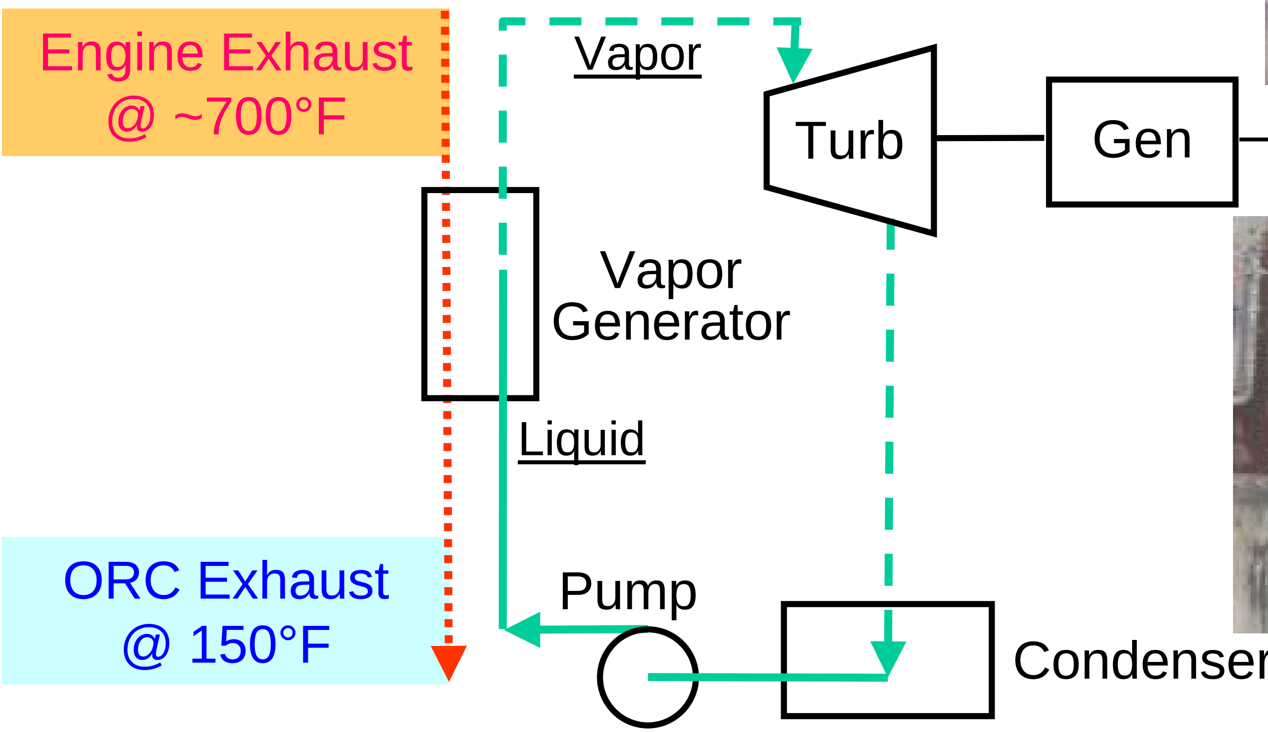
UTC Advanced Microturbine System: 3-Part Strategy

Cycle improvement + Organic Rankine Cycle Improve System Efficiency

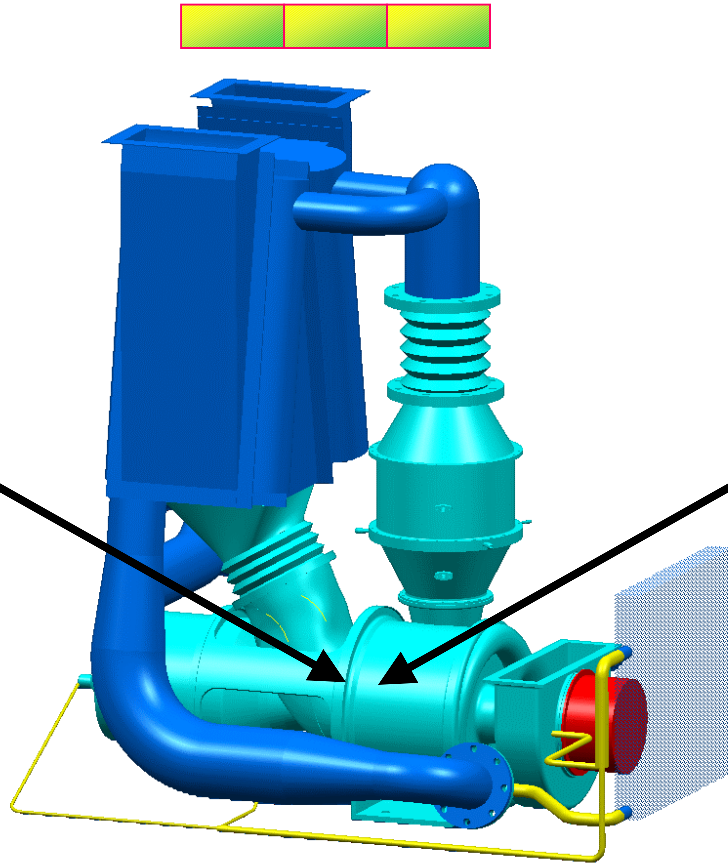
- Hotter Engine: Efficiency gain = 3 points
- Improved Electrical: Efficiency gain = 1 point
- Recover Waste Heat: Efficiency gain = 7 points

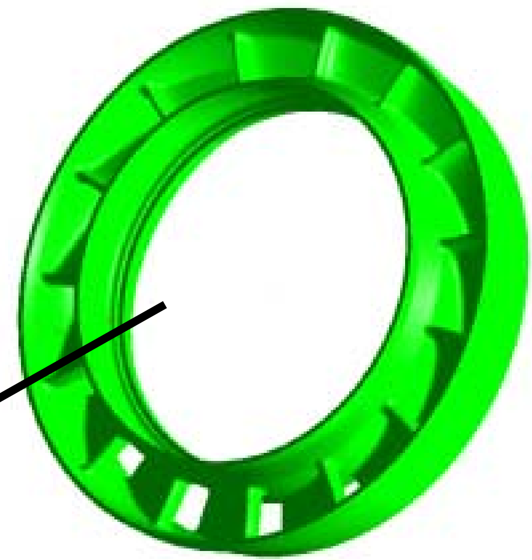


Organic Rankine Cycle (ORC) System



Ceramics Used for Vane and Integrally-Bladed Rotor (IBR)





Si_3N_4 IBR
Saint Gobain
(WB-NT154)

Integral Si_3N_4 Vanes
Kyocera (SN282)

Government Labs/Companion Programs

- ORNL-HTML – Characterizing silicon nitride materials, both with and without EBC
- NASA-UEET– Developing high temperature EBC for CMC
- Navy/DoE – Developing EBC for Silicon Nitride

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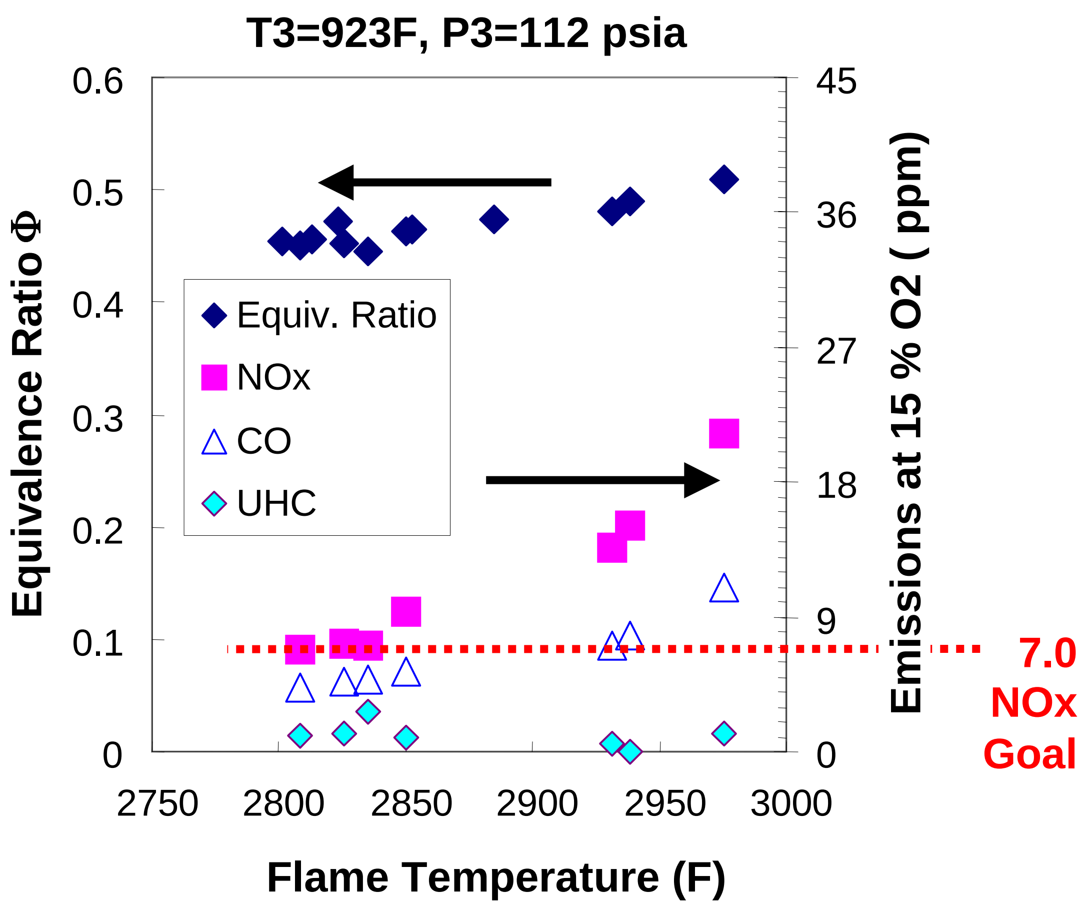
Fuel Staging to Sustain Low Emissions 70-100% Power

Preliminary Tests Near 7 ppm NOx

- NOx < 7 ppm and CO & UHC < 10 ppm
  - Attained NOx, CO, and UHC < 9 ppm over ~75-100% power turndown
- Low pressure oscillations (<0.3 psi amplitude) achieved over turndown range
- Preferred staging strategy identified for emissions and stability margin



Key Future Milestones Leading to Field Demonstration

2002

✓ Demonstrate 80 kW from ORC (February 02 – **Completed**)

- Demonstrate 5-point increase in system electrical efficiency with ORC (August 02)
- Perform integrated microturbine/ORC test (September 02)
- Demonstrate combustor emissions technology for NOx<7 ppm and CO<10 ppm (November 02)

2003

- Demonstrate ceramic turbine performance in core engine (June 03)

2004

- Demonstrate 40% electrical efficiency, low NOx performance in engine system (April 04)

2005

- Initiate >4000 hr field tests to demonstrate life (January 05)

What MTG is Right for a Fuel Cell Hybrid System?

- **The right system must balance performance, cost, and risk**
  - **MTG must be profitable - the markets are still developing!**
    - Broad product applicability
      - Fired MTG and FC Hybrid
      - Integration options
    - Affordable efficiency
      - Recuperator performance and life
  - **High system RAM - Reliability, Availability, Maintainability**
  - **Component and system stability under transients**